

Satellite Power System (SPS) Military Implications

October 1978

U.S. Department of Energy
Office of Energy Research
Satellite Power System Project Office
Washington, D.C. 20545

Under Contract No. EG-77-C-01-4024

DOE/NASA

SATELLITE POWER SYSTEM
Concept Development
and
Evaluation Program

Available from:

National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

Price:	Printed copy:	\$5.25
	Microfiche:	\$3.00

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Prepared for:
U.S. Department of Energy
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EXECUTIVE SUMMARY

This study examines the potential military role, both offensive and defensive, of a Satellite Power System (SPS). The findings are based on unclassified documents and reports, but are believed to be consistent with relevant classified work.

The very large orbital power source of the SPS could have a number of potential military applications. Perhaps the most arresting, but certainly one in the very distant future is the possibility of developing an anti-ballistic defense weapon utilizing laser or particle beams. Nearer term possibilities include anti-satellite weapons and perhaps some form of psychological weapons.

A number of potential military support possibilities are described. Power relay via laser beam to other satellites or to aircraft or remote land sites may be feasible. The satellite may provide a highly desirable platform for numerous support functions such as surveillance, communications, navigation and others.

An SPS with military capabilities may have a strong negative impact on international relations if it is not internationalized. Special treaties or agreements will probably be required to assure a viable SPS. Development of a national policy on military utilization of the SPS will impose certain international relations impacts.

The SPS satellite would be vulnerable to military action of an enemy with good space capability, but would experience little or no threat from saboteurs or terrorists, except via the ground controls. The satellite's intrinsic survivability is high because of its size, robustness and redundancy. Vulnerability of the ground segment is not greatly different from that of other large industrial complexes, but its importance suggests that strong protective measures would be provided for it.

The paper concludes with an outline of some of the key issues involved, and a number of recommendations for further study, including some areas for longer term efforts.

ACKNOWLEDGMENT

The author is deeply indebted to Dr. Robert M. Salter, Jr. for his assistance in the preparation of this paper. Special thanks are also due to the PRC Energy Analysis Company for provision of research materials.

TABLE OF CONTENTS

Executive Summary	iii
Acknowledgment	v
I. Introduction	1
II. Objective and Task Statement	3
III. Survey of Relevant Literature and Related Work	5
IV. Analysis and Evaluation	7
1. Task 1 - SPS Military Potential	7
2. Task 2 - Impact on International Relations	18
3. Task 3 - SPS Vulnerability	16
V. Key Issues and General Observations	33
VI. Recommendations for Further Study (Task 4)	37
VII. Longer Term Studies	39
VIII. Bibliography	41

I. INTRODUCTION

This report has been prepared for PRC Energy Analysis Company under P.O. No. W4121. It is intended to be one of the several inputs to the preliminary assessments being made in the Satellite Power System (SPS) Concept Development and Evaluation Program. This Program, a joint DOE-NASA plan, involves a series of studies over a three year period, to result in recommendations as to the utility and desirability of the SPS concept and the advisability of its development and implementation.

The report addresses military implications of the SPS, as one of the institutional/international issues having a significant bearing on the societal assessment area of the Program. The societal assessment in turn is one of the three major task areas, the others being environmental and comparative assessments, which make up the current system study, and which will be examined together in an iterative manner in order to help in arriving at a recommended system definition.

The SPS is a proposed means of providing utility electrical power from the inexhaustible solar resource. It consists of two principal segments. The space segment is a large, geo-synchronous satellite-borne solar cell array, together with microwave conversion equipment and an antenna for beaming the collected energy to earth. The ground segment is an appropriate receiving antenna array (rectenna), also with conversion equipment to transform the received microwave energy to a form suitable for utility use. After being transformed the converted power is fed to the local utility grid for distribution. The system is large -- the satellite array and the rectenna are on the order of 100 square kilometers each in size, and the net output power to the utility is to be 5,000 megawatts.

Although, as was stated, the focus of this study is an examination of the potential military aspects of the SPS, it was required that the study results be unclassified. In addition, no need-to-know authorization

was available, in part because of time constraints. Accordingly, most of the relevant literature examined was of an unclassified nature. Access to some classified reports was available to the author because of an existing relationship with the Rand Corporation, but these were a minor portion of the source literature. The substantial exclusion of classified materials from this study meant that some prior work could not be utilized, and precluded making more definitive statements in a few key areas. At the same time, an acquaintance with the classified literature assures that this study is consistent with related broad national goals.

II. OBJECTIVE AND TASK STATEMENT

The objective of this study is to determine what role the SPS has, if any, in the U.S. military posture, both offensively and defensively. To achieve this objective, four specific tasks are called out, as follows.

1. Investigate SPS potentialities as a weapon or other supportive element of U.S. military preparedness.
2. Investigate the potential for impacts on international relations.
3. Investigate the relative vulnerability to overt military action, terrorist attacks or sabotage.
4. Identify questions needing further study and an approach that can be taken (1) without security clearance and, (2) with security clearance.

III. SURVEY OF RELEVANT LITERATURE AND RELATED WORK

In carrying out this study, principal dependence for source data was to be placed on materials available in the open literature. The fact that the study report was to be unclassified meant that only limited use could be made of classified materials, since their substantive data was usually classified. However, researchers involved in relevant classified areas, while declining for the most part to discuss the subject on an unclassified basis, did aid the author in confirming that there was no breach of security while assuring relevance and consistency.

Sources which were used included a number of items from the extensive bibliography provided by the sponsor. A number of Rand studies were consulted -- these included both satellite-related works which were mostly classified, and studies relating to terrorism and sabotage, which for the most part are not. In addition to these, the usual open literature sources were utilized to a somewhat lesser extent.

As has been implied earlier, the available substantive literature on this question is not yet very extensive though growing. Although satellites and their applications have been with us for many years, the concept of very large utility systems is relatively new, and has received concerted attention only recently. Correspondingly, consideration of the military significance of such systems is also recent though of somewhat earlier origin. The bibliography is included at the end of the paper.

IV. ANALYSIS AND EVALUATION

To carry out the investigations required in this study, we address each of the tasks in turn, in effect asking how it applies, or what is its significance to the SPS. In some instances the SPS has to be evaluated as a whole, in others logic dictates that the different segments of the System be considered separately. The work of the first three tasks is described in this section, that of the fourth is in Section VI.

Task 1. The SPS potentialities as a weapon or other supportive element of U.S. military preparedness.

(a) Space Segment.

In examining this question, it is evident, to begin with, that the principal interest in the SPS from a military point of view is in the space segment. The ground segment, although having a number of unique features that distinguish it from other utility stations and comparable industrial complexes, has little that could be considered particularly significant militarily. Perhaps the one feature that could be an exception to this statement lies in the requirement for communication between the ground segment (the rectenna) and the satellite. Pilot beam signals are required to be sent from the rectenna center to the satellite antenna array to provide control for the power beam. Also, telemetry receiving and transmitting equipment is required for overall command and control of the satellite, and it may be advantageous to locate this function at the rectenna site. To the extent that the rectenna is connected to the satellite for these two functions, it may have some role militarily, but only because of the connection. We will return to this question later.

The space segment of the SPS, i.e., the synchronous altitude satellite, has substantial potential military implications, mainly because of its very large power capability and its orbit. Although many satellites have been and continue to be utilized at synchronous altitude, none has ever remotely approached nor required the power level projected for the SPS satellite. Power levels for present-day synchronous satellites are generally measured in hundreds of watts. The potential of having many gigawatts available on orbit is a totally new prospect. Some of the possible potentialities are outlined in the following, in which weapon possibilities are described first, followed by possibilities for other military support elements.

(i) Weapon possibilities

One of the most challenging prospects for military application of the SPS satellite is the possibility of development of a satellite-borne beam weapon for anti-ballistic-missile (ABM) use. One possible version of such a weapon would be a high-energy laser beam, functioning as a thermal weapon, to disable or destroy enemy missiles. The synchronous orbit provides an excellent vantage point from which substantially an entire hemisphere of the earth can be continuously scanned from one satellite, and the available primary power (assuming the full output of the satellite can be devoted to the laser for this use) means that beam output powers up to gigawatts might be possible. However, calculated values for the laser power required for missile kill from synchronous altitude, even though very imprecise, indicate that the required laser performance is still a long way off. For example, a

boost-phase kill from such an altitude may require laser beam power of the order of tens of gigawatts, for a typical set of parameters. Extrapolations from today's laser beam powers, perhaps up to one megawatt, to the range of several gigawatts are very uncertain, and make clear that an effective laser system at such altitudes must be considered a rather remote possibility. For such high energies, other approaches such as the Synchro-beam concept which utilizes synchrotron radiation may turn out to have some advantage over the laser, but are more speculative at present. Other arrangements in which, for example, an intermediate laser relay platform might be used, could possibly offer some advantages. However, these are beyond the scope of the present study.

An alternative to the use of lasers would involve particle beams. Although these have been suggested in the past for weapon use in satellites, a prime stumbling-block has also been the large power requirement. As with lasers, in the SPS case the primary power available is probably sufficient for any foreseeable weapon system, so that other system elements become limiting. The energy required from a particle beam for missile kill or disablement may be less than that from a laser beam because of its penetrating power, but this may be outweighed by other factors.

Theoretically, highly collimated relativistic electron beams can be propagated over long distances utilizing so-called space-charge focusing arising from partial neutralization of the beam's coulomb charge by ambient positive ions in space regions. Such an electron beam, if "stiff" enough, i.e., at GeV particle levels,

could overcome some of the propagation limitations imposed from particle trajectory bending in the earth's magnetic field. Consideration has been given in unclassified sources to propagation of electron weapon beams in the earth's atmosphere through use of a laser beam to preheat a path and "pave the way" for the following electron beam. This consideration might permit attack on surface and airborne targets from the SPS.

Neutral beam weapons in space have also been discussed in unclassified periodicals, but such beams would not remain collimated over large distances (as is potentially possible with an electron beam). Even a low divergence beam of one microradian will still spread out much too far at moderate ranges. At very high beam currents, such a beam might be useful against relatively hard in-space targets.

In summary, it can be said that, at this time either a particle or laser beam ABM system is an intriguing prospect, but requires far more development before a proper assessment of its feasibility or practicality can be made. The effectiveness of such an ABM system directed instead against aircraft is probably not sufficiently different from that against missiles in the boost phase to justify any different conclusion.

A second potential weapon application of the SPS satellite is as an anti-satellite weapon. This also would require a high-energy laser or particle beam, as before, to be used for disabling or destroying militarily important enemy satellites during states of war. For the most part, the kill/range considerations are similar to those for missiles, except that satellites

are probably softer targets than re-entry vehicles, so that the effective ranges against satellites would be greater. The SPS satellite itself is of course not intended to be highly maneuverable, so that its sphere of influence is limited to the space around it.

The anti-satellite weapon capability may of course also be used for self-defense purposes. In this role the range requirement is greatly reduced. It is necessary to disable or destroy an incoming weapon only far enough away to remain out of the range of its lethal or damaging effects. In practice this means that kill ranges of a few kilometers against conventional weapon carriers and a few hundred kilometers against nuclear weapon carriers may be adequate for this function. Thus, the self-defense function may be done with considerably less power than the anti-satellite weapon.

A third possible weapon application of the SPS satellite is perhaps best considered as a psychological weapon, directed principally at enemy personnel. Two possible variants are indicated here. In the first, it is suggested that it might be feasible to redirect the main microwave power beam away from its rectenna and onto areas where enemy personnel are present, either in military operations, or, possibly, civilian activities of various kinds. This might also be done by a smaller, perhaps lower-powered beam from an antenna designed for the purpose, so as not to interrupt the main power beam. The objective of this tactic would be to try to disrupt normal operations and activities by inducing fear or panic, and causing personnel to seek shelter from the radiation. Appropriate shelter from the microwave

radiation is not usually readily available, so that the psychological effect may be quite strong.

The second means suggested for accomplishing a somewhat similar result is to utilize a high energy laser beam from the satellite, instead of the main power beam, as an anti-personnel weapon. It might be particularly effective if an IR wavelength were used, so that the beam is not visible. As a further extension of this approach, it might be feasible to transmit high enough energy to ignite combustible materials, thus adding to the psychological effect. A high-energy particle beam might also be used in place of or in addition to the laser beam.

(ii) Supportive elements

The ways in which the SPS space segment might provide supportive elements for U.S. military preparedness fall broadly into two areas. One of these is a direct result of the high power available on the satellite, and the other comes about because at synchronous altitude the satellite represents a very desirable platform with the added advantages of ample power and payload capability. Most of the unclassified applications or functions noted here are not new, but are included for completeness, or because new or improved capabilities may be possible as a result of the greater power, weight and supporting services available at the orbital altitude.

The first area of interest that may have interesting defensive military implications is the concept of a power relay using laser beams as the transmission means. While

power transmission by means of a microwave beam is of course a key element of the SPS, the use of laser beams for transmission, with their different characteristics, gives rise to systems with quite different advantages. Among the notable differences between laser and microwave transmission are the beam and target sizes -- those for the laser being a very small fraction of the corresponding microwave dimensions. These smaller dimensions for laser power transmission are essential elements in the proposed ideas. Three possible applications of laser power relay are noted in the following paragraphs.

The first application is one in which the laser beam power relay would be made from the SPS satellite to other satellites or platforms, for military uses. One such use might be the so-called hunter-killer satellites. For such applications, conversion to electricity on the receiving satellite is probably the preferred route. Conversion efficiencies for a relatively low-power thermoelectronic converter for this purpose have been calculated at over 40%, and it is likely that scale-up to several megawatts is possible.

It is evident then that this kind of approach may be capable of providing ample amounts of power to various satellites, either on a continuous or intermittent on-demand basis, and thus remove what has always been a difficult and frustrating design restriction. The effects might be to simplify the receiving satellites or reduce their costs, extend their lifetimes, expand their capabilities, provide silent unenergized spares for survivability improvement, or combinations of these and other factors.

The second application relates to the possible use of laser power relay to aircraft. One example of this kind of proposed usage has been described in a system in which a large commercial air transport may be powered during cruising flight by a continuous high energy laser beam. The aircraft utilizes conventional jet engines for take-off and climb to cruising altitude. It is equipped with a laser-powered turbofan engine which takes over for the cruise regime. The turbofan receives the focused laser energy directly in its "combustion" chamber thus producing the required high temperature gas for its operation.

For a military mission, such as that of the Airborne Early Warning and Command aircraft for example, laser relay power from the SPS satellite would permit a substantial operational improvement, since it would allow essentially unlimited on-station (cruise) time. Also, different operational procedures might be possible and desirable. For example, it might be quite feasible and effective to keep some bombers aloft constantly, loitering near a location of interest.

The third application of laser power relay would be to transmit power to remote military operations on earth. Here the possible advantage would be to provide power where perhaps long supply lines are the only alternative, or particular demands for mobility, or covertness militate against earth-based supply. The method to be used for conversion from laser energy would likely be determined by the end use required.

The second main area of interest in the SPS satellite for military support comes about because of

its desirability as a platform on which or from which various operations might be carried out. As was suggested earlier, the reason for iterating these here is not to imply that they are newly-conceived functions, but rather to point out that they may acquire new or improved capabilities because of the advantages offered by the SPS platform.

An example of the use of the satellite as a platform for functions of military interest would be for an inspection station from which examination of other satellites or vehicles could be carried out. Its large payload and power capacity means that a variety of both passive and active sensing systems could be carried. The fact that manned assembly of the satellite is planned to take place at synchronous altitude implies the possibility of a manned inspection station, which would certainly enhance the inspection potential. It may well be that routine maintenance and repair functions for the SPS satellite would require that the satellite be manned more or less continuously. It may also be of some interest in this context to consider the possibility of providing a repair function for other satellites, although accessibility to them may be a problem. Presumably some type of space retrieval and repositioning vehicle system would be required, so that satellites requiring repair could be brought to the SPS, and after repair be replaced in their proper orbital locations.

Another example of a supporting military function that might be advantageously carried on the SPS satellite is that of surveillance and early warning. Here again the resources available on the platform make possible

carrying a wide range of sensing systems so that it may be expected that substantial gains in performance would be possible. Security classification restrictions prevent discussion of specific possibilities.

Other militarily important functions that might be advantageously implemented via the SPS platform would include:

Communications

Jamming

Navigation

Meteorological/Geological/Geographical Survey

ELF Link to Submarines

A potentially very important military function falling in a certain sense under the Communications heading is that of jamming of enemy communications. With the scale of power represented by the SPS and its near-hemispheric coverage, its military utility for jamming and creating communications havoc is potentially great. It could perhaps be redirected to jam nearby space systems -- particularly the up-links. Certainly terrestrial communications, both tactical and strategic, could be affected in a major way.

The inclusion of a number of functions on one satellite, of course, raises the question of vulnerability and survivability. Specific decisions about numbers of functions to be placed on one satellite platform will be guided by considerations of vulnerability and survivability, numbers of satellites available, costs versus risks, etc. It is noted that a mature SPS calls for many satellites in orbit; with such

ample redundancy a range of options is likely to be available.

(b) Ground segment.

As has been indicated in the preceding sections, the principal potentials of military significance of the SPS lies in the space segment. However, one feature of the ground segment should be noted as possibly being of interest as a supportive element in the military context. This is involved with the communication provisions between the rectenna and satellite.

The system requires that a coded microwave pilot beam be sent from the rectenna center to the satellite antenna array to provide control of the power beam. (Coding is to prevent interference with the power beam operation by unauthorized persons, such as saboteurs or terrorists.) Also, it may be that telemetry equipment for overall control of the satellite would be located at the rectenna as well. Thus, the rectenna may be a key communications center for SPS operation. With extensive and unique communications capability in place, it may be logical to provide specialized, secure links for military use at such sites. These links may extend only to the satellite under control and to its piggyback systems, or may utilize the satellite as a relay for a more extensive system, including links to other points. It might be of considerable interest to explore whether or not the main power beam could be utilized in any way to provide a secure down link.

Task 2. Impacts on International Relations

A basic difficulty exists in planning for SPS development with regard to the applicability of existing international treaties and space laws. These agreements and conventions were adopted to cover conditions for space usage in an era dominated by scientific, communication, navigation, and surveillance satellites having relatively modest transmission link powers. This body of space jurisprudence did not anticipate systems of the magnitude and numbers of vehicles projected for SPS. In fact, there is some concern that the existing regulatory structure is even adequate for the burgeoning communication field let alone the great increases estimated for programs of the scale contemplated for the SPS (and other) concept(s). This difficulty is further aggravated by the fact that the problem must be resolved *now* in order to assure the future for SPS and to permit pursuit of the extensive fiscal and programmatic commitments necessary for its accomplishment.

It will probably be desirable to adopt extraordinary procedures and measures to guarantee the SPS concept viability. Such measures could include special treaties with major world powers and/or internationalizing of SPS. It will be necessary to make accurate forecasts of societal and economic demands of the twenty-first century, and the status of technology and international law in that era to establish a framework within which the SPS can be structured.

A militarily-oriented SPS would inevitably have a much stronger impact on international relations than one with no military capability, unless of course it were truly international, in which case the military aspect tends to lose its significance. For an SPS which has, or is thought to have some military capability, it is believed that there are at least three areas of particular concern:

- Communication Interactions (EM Spectrum Usage)
- Orbital Position Allocations
- Self-Defense Measures Permitted

Although the first two of these areas are covered to some extent under existing treaties and regulatory mechanisms (as noted above), these may be ill-suited to cope with systems of the scale and characteristics of SPS. In the following section, the three areas are discussed in more detail.

SPS Communication Interactions

The radio-frequency crowding due to Comsat and Intelsat along with their military counterparts and with other space systems is already approaching critical proportions. Crowding exists both in frequency spectrum and in position assignments along the geosynchronous track. This is expected to get worse as a consequence of growth in telecommunications frequency requirements and from data nets, cable television, interactive satellites (such as the Canadian Anik), navsats, metsats, and upgraded Landsat systems.

There is present speculation as to future solutions of this problem alone -- even without the introduction of SPS. Some space planners have suggested reserving space utilization for space-unique functions. This would mean abandonment of commercial (and peace-time military) telecommunications and replacing them with land-lines and under-sea cables. Such a transition would be enhanced by recent developments in laser fiber-optic cables, packet-switching computer systems, and microminaturization of sending and receiving equipment.

These cable systems will probably be demanded in any case with the advent of video telephone which will require orders-of-magnitude increase in communication traffic volume -- and also will not tolerate the one-quarter-second communication delays inherent in comsats on geosynchronous orbits.

Further, the burgeoning in telecommunication data volumes will be aggravated because of future electronic mail and computerized textual editing and handling systems. Other forms of data communications will

also increase. Computing power (instruction complexity, etc.) continues to increase a thousand-fold every ten years.

Military usage of space telecommunications will continue in the future but with hardened links which will include transmission media other than rf -- laser beams, for example. Military employment of (protected) land and sea cable systems is likely to increase, reflecting the computerized communication and laser data link improvements discussed above.

All of this adds up to the observation that although some types of future commercial communications via space may be phased out in favor of greatly improved terrestrial cable, space usage for rf communications will continue to be critical -- particularly for projected Landsat requirements. Superposition of SPS in its presently contemplated form will introduce a quantum jump in rf telecommunication interference and spectrum crowding.

One possible way to alleviate these problems temporarily might be to invite other users to share SPS platforms and to employ SPS power links as modulated carriers. Perhaps some fraction of SPS solar-derived energy could be transmitted by laser beams which are then simultaneously employed for data transmission; the value of such transmission might offset the lower laser link efficiency for power transfer purposes. At the long link distances involved, reduction in temporal coherency of the laser beam might render such links as useless for communication purposes, however.

Future space users will necessarily tend towards GHz frequencies (such as kU band) and toward laser links (from lower orbit altitudes) for wide-band data transmission. However, interference from SPS higher harmonic side-bands or from sum-and-difference frequencies from interfering pairs of SPS transmissions will continue to represent a problem for the bulk of space users.

The regulatory machinery for present space frequency allocation

is geared to existing space systems and to reasonable future extrapolations from this base. It will be *necessary* for the U.S. to air the potential SPS rf interference problem from the outset and to seek binding international agreements to allow clear channels at the SPS 2.45 MHz fundamental transmission frequency and its higher harmonics before embarking on the prodigious enterprise that SPS represents. The potential problem for rf interference by the SPS, unless resolved by prior treaties with major powers, courts danger that such powers can, in times of hostilities, use such interference as an excuse for action against the SPS.

In the above discussion in-space interference with other space systems is highlighted. However, there are a number of other ways in which SPS can interact with other rf emitters and receivers including through antenna side lobes to ground equipment, physical changes in ionospheric regions used for broadcast radio reflection, and interaction in these same regions with higher frequency signals through the anomalous absorption phenomenon -- to name a few. All of these potential communication encroachments must be identified and treated in the ensuing international agreements.

In addition, it is possible that high power beams employed by the SPS -- particularly at laser wavelengths -- could disturb upper atmospheric energy balances via radiative transport phenomena in a similar fashion to that forecast for SST thermal pollution. The extent to which this particular problem would exist for regions not directly over U.S. ground receiving stations is not known, but as in the communication interference case it could be a propaganda point for a hostile power, particularly one vying for third-world support against the U.S.

If SPS is internationalized in an effort to share the benefits -- and the responsibilities -- among other nations, presumably these nations will also have receiving stations. This will certainly be a requirement if such countries are on different continents; but even with

adjacent lands, it is uneconomical to transmit power over excessively long land-lines. In these other regions of the world the above environmental and communication interference with surface (and airborne) systems may be more acute.

It was noted earlier that tactical and strategic military space systems could be quite susceptible to jamming from upper space, such as might be provided by the SPS. This, of course, is a symmetrical problem -- we can interfere with military systems of foreign powers or vice versa. If SPS is internationalized, then another nation having such a system could employ it against us. Alternatively, a hostile power could commandeer SPS elements -- take over a country that has one, capture control of the space system, etc.

Orbital Position Allocations

The baseline design of the SPS calls for satellite operation in geostationary orbit. Because that orbit is already heavily used, and the total number of positions available in it is limited (though the limit is not well-defined), it must be considered as a limited resource, in an analogous sense to that of the electromagnetic spectrum. The minimum separation between satellites depends on factors such as satellite-to-satellite occultation, rf signal formats, transmission power, station-keeping performance, etc., with a principal criterion being the amount of rf interference that can be tolerated between satellites.

At the present time, there is disagreement as to the actual minimum spacing needed for satellites in geostationary orbit. Calculated values range from 2° to 0.2°. The orbit is currently occupied by upwards of 100 active satellites, and this number is likely to more than double in the next ten to twelve years. Improvements in technology should reduce the required minimum spacing, though probably not to a major extent.

Since the detailed characteristics of the satellites that might occupy the orbit cannot be known beforehand, it is not possible to specify exact separations that will be needed, and therefore the future capacity of the orbit cannot be precisely determined. What is urgently needed is proper international specification and regulation of geostationary satellites, so that the limited orbital space can be utilized in an optimal way. This is particularly significant for the SPS system because of both its very large radiated microwave power, which may place additional constraints on orbit separation, and the need, in a mature system, for positions for as many as twenty to thirty satellites.

It should be noted that some early steps have been taken towards international management of the geostationary orbit, and it is to be expected that they will be extended further with the ultimate aim of a fully regulated system. The achievement of this ultimate goal, as with many international ventures is likely to be a lengthy and complex process, however, and one that is made much more difficult by the inclusion of militarily-oriented satellites.

A military SPS, or at least one with acknowledged military capability, makes the requirement for orbit space more demanding, while at the same time increasing the difficulty of obtaining such space. Presumably most, if not all nations would, in their own best interests, resist having a military capability placed in orbit by another unless it were to offer them some particular benefit which outweighed the military threat. If military capability is not acknowledged, but only suspected, the resistance to it may be just as great and in some cases greater, because of suspicion of the unknown. The fact that the SPS is a space system, with the potential of carrying powerful new and unknown kinds of weapons, with a very large power capability, and potentially having "access" to (threatening?) most areas of the earth, would indicate that it constitutes a difficult question for international agreement. Unless the SPS is truly internationalized to a large degree,

questions such as this may make its effective development in an orderly world difficult if not impossible.

SPS Self-Defense

The present treaties prohibiting space systems bearing "nuclear weapons or weapons of mass-destruction", while permitting self-defense weapons, are in a similar status to the communication spectrum agreements discussed earlier in that these treaties were made in an era that did not contemplate systems like the SPS. For one thing, the scale of SPS is such that new definitions, relationships, and weapon concepts may need to be elaborated.

Self-defense systems designed to protect SPS vehicles might also be considered as "weapons of mass-destruction". For example, the SPS power beam itself might be construed as a potential weapon of mass-destruction if it were to be redirected either by U.S. military forces, or by others who may have commandeered the space platform.

In this category also, a potential problem area is the suggested use of SPS to laser-power aircraft during high-altitude cruise phases as described in Section IV-1. It is possible that the same lasers employed for aircraft propulsion could be redirected for SPS self-protection. However, when used with bombers or cruise missile carriers, the SPS could be viewed as a component of a weapon of mass-destruction although the weapon itself is not in space.

Also, there is concern that the aircraft-powering laser spot be sufficiently smaller than the aircraft's collector, and that control mechanisms be accurate enough, that there is no over-spill. At aircraft progression rates the dwell time for such over-spill to illuminate personnel on the ground would be a number of milliseconds, while it is estimated that injury would result from only a fraction of this exposure time. Each SPS platform would have the power capacity to continuously operate 50 such lasers (or 1,000 for a fleet of 20 SPS's).

Particle beams of electrons or neutralized protons might be employed for self-defense, and providing that the particle energy is held below GeV levels, the atmosphere and/or earth's magnetic field may provide adequate shielding for ground systems. However, the existence whether real or only suspected, of particle beam weapons on an orbital platform, is likely to raise suspicions about the operator of the platform even though the weapons have no capability against earth targets. Here again, the appearance of aggressive intent, in a nationalistic environment could cause a substantial negative impact on international relations.

Task 3. Relative vulnerability of the SPS to overt military action, terrorist attacks or sabotage.

In this task as in Task 1, we examine each of the main segments of the SPS individually since vulnerability considerations for them differ. As before, the breakdown is into the space segment and the ground segment. The space segment includes the SPS satellite, the necessary ground-based communications facilities for satellite control, and any essential on-orbit assembly or maintenance facilities, since these are unique to the SPS, and may be significant in vulnerability considerations. The ground segment includes the rectenna complex and the necessary interconnections to the utility grid, but not manufacturing and construction facilities since they are basically not unlike those for other systems and thus do not introduce unique new situations or problems.

(a) Space Segment.

In considering the SPS satellite itself, the principal area of concern about vulnerability has to do with overt military action. It is highly unlikely that terrorism could pose a direct threat to the satellite on orbit because of its inaccessibility, although it certainly could during the manufacture and preparation on earth, and might possibly be a factor during orbital assembly. Similarly, the potential for sabotage may possibly extend to the on-orbit assembly phase, but is very unlikely in orbital operations.

On the other hand, indirect terrorist or saboteur action could be taken against the satellite via the ground control facility. This could be done for example, by physically attacking and gaining control of the facility so as to send incorrect or damaging commands to the satellite, or by damaging or destroying the facility, interrupting its power,

or otherwise interfering with its operation so that no commands could be sent. Similarly, attacks could be directed at the rectenna, so as to interrupt the pilot beam operation. The susceptibility of the satellite to such kinds of adverse actions will be to some extent a function of the system design philosophy, since the different satellite functions can be designed to varying levels of independence from earth command. The design can, of course, also be utilized to make the actual operation of command equipment difficult for anyone but highly skilled operators, and thus place another obstacle in the terrorists' way.

Sabotage of the satellite is also considered a rather unlikely threat. Although certainly the preparation and manufacture of the myriad of components for the satellite gives ample opportunities for saboteurs because of the great quantities involved, the nature of the satellite is such that at successively later stages in its construction and operation, these opportunities become successively more restricted. Parts and materials are subjected to extensive inspection and testing because of their end use, and this should be quite effective against sabotage. Also, the final assembly is to be done on orbit, a highly isolated environment to say the least, by operators who are necessarily carefully screened and selected, allowing even less scope for saboteurs in this phase.

The threat of overt military action against the space segment -- both satellite and ground-based control system -- is real, although as would be expected, its execution would clearly constitute an act of war. Satellites with hunter-killer capability up to synchronous altitudes, if not operationally available today, almost certainly will be within the time span of interest here. Thus, although various

hardening measures and self-defense provisions can be implemented, it is undoubtedly safe to say that absolute protection of the satellite cannot be assured. In this as in other kinds of military exchanges some weapons must be expected to get through.

The large scale of the satellite tends to make it somewhat less vulnerable than would be the case otherwise. This is so because of both its physical size and the very high power generated. The large size means that redundant subsystems can readily be provided, and indeed may be mandatory for reliability reasons. The high power level means that many paralleled (redundant) energy circuits can be used in the design. Both of these factors act to prevent a total loss of power operation in the event of weapon damage short of total destruction. The one principal item which is not provided with redundant back-up in the current base-line concept is the transmitting antenna, and although it is a relatively massive structure, it may be the most vulnerable component of the satellite. It may be argued that a redundant antenna design ought to be considered for survivability reasons. The large scale also means of course that substantial weapons are needed to do more than partially disable the satellite. It may turn out that because of this large size, the high orbital altitude and the fact of being in a space environment, nuclear weapons would be the only likely ones with a good probability of achieving assured destruction.

If the satellite were to require manned operation, it appears that the vulnerability to military action could be greatly increased. This comes about basically because the human body is very fragile in a space environment, and cannot survive without extensive and elaborate life-support

systems. Such systems would be very difficult to harden adequately against the range of weapons that might be used against them. Accordingly, the life-support systems would probably be a preferred soft spot in such a manned satellite.

(b) Ground Segment.

The ground segment as considered here consists basically of the rectenna complex with associated interconnections to the utility grid. For the most part, such interconnections will be within and part of the rectenna complex. Distribution systems to more than one utility for example, if located away from the rectenna are considered part of the overall utility system rather than the rectenna.

The vulnerability of the rectenna facility to overt military action is essentially not greatly different from that of other large industrial complexes or other utilities. Clearly the facility itself is subject to a large range of military actions, and presents a larger target than most present-day utilities. Although its operation is not dependent on a critical fuel supply line such as coal or oil, which can be rather easily interdicted, it does require other kinds of materials and supplies for maintenance and continued operation. Concealment, hardening, protective sheltering and other similar measures provide limited protection. Although the rectenna is most likely to be part of an interconnected utility grid, so that the loss of any one station is not necessarily critical, its large capacity makes it a very attractive target. The history of recent wars gives ample evidence of the desirability of reducing an opponent's industrial capacity by action against his power generation systems.

Susceptibility to terrorist attack or sabotage of the

ground segment and its operations is probably not substantially different from that of other utility stations or industrial complexes. In one respect the terrorist threat may be somewhat less for a rectenna facility than for other smaller utility stations for example. The large physical size and power capacity of the rectenna, plus its likely key role in controlling the incoming power beam imply that it would be logical to provide a substantial protective force for it in order to assure continuous operation. This might take the form of protective barriers around the rectenna, guard forces, warning and alert systems, and other such installation security measures. The existence of such measures may tend to make the job of terrorists very difficult, and may deter all but the most determined and sophisticated ones, and lessen the impact of those attacks which are undertaken. Saboteur activities also would probably be hampered somewhat by such measures, although perhaps not as substantially as those of the terrorists. In neither case is the threat removed, but its dimensions may be altered.

Fear of the unknown effects of microwave radiation might also operate to inhibit terrorist actions to some extent. At present, the full range of effects of microwave energy on humans is not understood. For example, the acceptable maximum exposure limits to microwave power in the U.S. versus those in the Soviet and some other European nations differ by a factor of one thousand. This lack of understanding and agreement finds part of its expression in widespread public suspicion and perhaps fear of microwave radiation, somewhat akin to that regarding nuclear radiation. To the extent that such suspicion or apprehension is still present at the time of an operational SPS, some terrorist actions involving

physical presence at the rectenna site may well be avoided. This would not of course have any effect on the use of weapons or other tactics at a distance, or perhaps attacks involving limited exposure to the radiation, though it might lessen their severity.

In pre-operational stages of manufacture, assembly and test, the ground segment is expected to be as vulnerable to the threats of adverse actions as other kinds of industrial products or systems. There is nothing particularly unique about the rectenna components and sub-assemblies that might place them in a different category of hazard.

V. KEY ISSUES AND GENERAL OBSERVATIONS

There are many questions with military significance impinging upon the concept, structure and operation of a future SPS system. Among the chief ones are those listed in the following section, where they are shown grouped into four different categories. It should be emphasized that many of these questions are interrelated and thus cannot be resolved independently; also the grouping is not necessarily the preferred one. The order of listing has no particular significance.

Military Implications

- Of what value would an SPS ABM weapon be?
- Is there any U.S. military benefit to be had from an international SPS?
- Should a laser power relay be developed for military use?
- Of what value are psychological weapons on the SPS?
- Should military aspects of an SPS be overt or covert?
- Does military application of the SPS justify its economics?

National Policy

- Should an SPS be national or international?
- Should an SPS have any weapon-related functions?
- Should the U.S. start an SPS with the ultimate aim of making it international?
- Would a U.S. SPS have a negative effect on foreign relations?

International Issues

- How should the EM spectrum usage be determined to accommodate SPS equitably?
- How should geostationary orbit usage be resolved?
- Should the SPS carry international/shared weapons?
- Would any nation be trusted to have such large power sources on orbit?

- What provisions should be made for accidental loss of control of the power beam?

Technology Questions

- Is an ABM weapon feasible using the SPS?
- Is a power relay to aircraft or other satellites feasible?
- Can an SPS operate unmanned?
- How can loss of control of the power beam be prevented?

As indicated earlier, SPS platforms could be modified to host a number of military as well as utility users. In fact, combining SPS with military functions could enhance both sets of systems. Although the SPS is projected to be economically competitive as a major U.S. energy source -- and certainly one that would not deplete U.S. energy resources -- there may be considerable inertia to overcome in initiating a project of this scope and novel nature. Correspondingly, large space weapon platforms, such as for midcourse ABM, will also be difficult to "sell", again because of magnitude, but also because they may sit for years in space awaiting the alarm. The combination of two such functions may be highly synergistic from a programmatic standpoint.

The development of an SPS system would represent a major commitment whether undertaken as a national or international project. The choice, on the part of the U.S., as to whether to attempt such a program alone, or in concert with others on an international basis, will require some prior decision as to possible military utilization. It seems clear for example that if the U.S. intent is to take full advantage of whatever military potential may be available from the SPS, then she should implement the system alone, or perhaps with some selected allies. In this way independent control of the overall system operation as well as that of the military adjuncts could be readily maintained. On the other hand, if the intent from the outset is for an international system, then it seems equally clear that

military applications would play no part in the SPS system.

If the SPS were to be successfully implemented, whether with or without associated military functions, it seems inevitable that this would give a very strong impetus to the development of some form of ABM weapon. The rationale for this (apart entirely from simply a continuation of recent and current efforts in this direction) is just the fact of the existence of a very large power source on orbit, and the demonstrated success of high power microwave transmission. These two factors inevitably imply high power beam weapon potential. Laser or particle beams would be the likely candidates. The achievement of a successful ABM system could have far-reaching consequences. Although it is clearly many years in the future, this factor deserves the most careful attention, since it may be extremely important in determining the course of SPS development.

VI. RECOMMENDATIONS FOR FURTHER STUDY

It is recommended that the following topics be considered for study during fiscal year 1979 in order to aid in providing answers to the key issues identified in this study.

- What is the worth of the expected military contribution of the SPS system?
- Identify the factors that would be used to determine the desirable extent of military application of the SPS.
- Provide an evaluation of the worth of having a power relay from the SPS satellite to other satellites and to aircraft.
- Determine the potential impact of SPS on future world military postures. Would it have a de-stabilizing effect? Would it have potential benefits in times of international alerts?
- Is it feasible to consider developing an "international ABM weapon" rather than a U.S. version, and if so what are the relative advantages and disadvantages?
- Give a comparison of the advantages and disadvantages of having a U.S. SPS system versus an international one.
- What are the prospects for developing a successful ABM weapon with the SPS system?
- How can the problem of rf spectrum crowding be resolved satisfactorily so that the SPS spectrum requirements can be satisfied?
- How can the geostationary orbit positions be determined or allocated in such a way that the SPS will be assured of sufficient space(s)?
- What are the prospects that the SPS could operate unmanned?
- Identify the provisions that are necessary to assure adequate invulnerability of the SPS system.

Security Clearance

In considering the two study approaches to be taken, either with or without security clearances, it would be appropriate to consider a somewhat different study content for the two cases. For the approach to be taken without security clearance, the study should emphasize an SPS without military functions or adjuncts, or at least a minimal military content. It could possibly be a solely U.S. venture, but perhaps more likely U.S. plus other nations, or a truly international system. Because the entire classified area is avoided, the study output is maximized in the areas where the greatest effort is applied. Although the avoidance of classified areas can simplify the work considerably, the other side of the coin is that an effort aimed at multi-national involvement introduces another different set of problems. It may also delay the program, at a later time when military application questions are raised and will have to be answered.

A study to be done with security clearance should be directed at identifying or recommending opportunities of military utility which the SPS may present. The study should examine all possible military aspects of the SPS, involving all pertinent classified materials and sources. It should analyze as clearly as possible all of the pros and cons for each potential application that can be identified. With such analyses available, decisions on system questions can then be made at the national level which are consistent with national aims and objectives. It seems self-evident that a militarily-oriented SPS system would necessarily be a closely-held U.S. program, or at the most one involving a small number of close allies.

VII. LONGER TERM STUDIES

As one outcome of this brief preliminary study of the proposed SPS system, it is suggested that there are several areas that are deserving of a much more extensive study because of their importance to the system.

In the first of these we emphasize the importance of a thorough evaluation of the ABM weapon potential of the SPS system. This potential may be such that at one extreme it might cause the abandonment or elimination of ICBM systems as we know them. It would undoubtedly involve major policy questions and decisions as well as strictly technical and engineering matters.

The second study area suggested involves the use of the rf spectrum, and in particular how provisions can be made for the SPS (and other systems) to be provided with necessary frequency allocations when they are needed. As has been indicated earlier in this paper, the difficulties attendant on rf spectrum usage, crowding, interference, etc. have become severe, and threaten to get much worse. They may become so critical as literally to prevent the implementation of new systems. It is essential that means be established to prevent such an occurrence.

A third study area, probably classified, would involve examining the kinds of services that the SPS could provide that might be of benefit in tactical or strategic warfare. For example, could laser power relay be extended to cruise missiles and actually be useful on a worldwide basis?

The fourth study would investigate what measures an aggressor might take against an SPS such as degrading its performance, or capturing or in some way holding the system hostage.

Finally, a fifth study is suggested that would investigate the organization and control of a shared civil/military SPS system. It may turn out that the projected development costs of an SPS system are too

high for the civil sector alone, so that they are shared by the military. For this eventuality it is of interest to examine how the SPS system could be organized to operate in different situations.

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